Scalar top quarks at the Run II of the Tevatron in the high $\tan\beta$ regime

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Abstract

We discuss the decays of the lightest scalar top quark $\tilde{t}_1$ in the Minimal Supersymmetric extension of the Standard Model and show that the final state $b\tau\nu_\tau\chi_1^0$, where χ_1^0 is the lightest supersymmetric particle, can be dominant in a significant area of the parameter space, in particular in the high $\tan\beta$ regime. We then analyze the prospects for discovering relatively light scalar top quarks accessible at the Tevatron Run II in the $b\tau$ and missing energy channel.

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1. Introduction

In the Minimal Supersymmetric (SUSY) extension of the Standard Model (MSSM) [1], the phenomenology of the spin-zero partners of the top quark is rather special [2]. Because of the large t–quark Yukawa coupling, the evolution from the high (unification) scale to the electroweak scale of the soft–supersymmetry breaking scalar masses of left– and right–handed top squarks, $\tilde{t}_L$ and $\tilde{t}_R$, is different from the one of the partners of the light fermions [3]. In addition, the two current eigenstates $\tilde{t}_L$ and $\tilde{t}_R$ mix very strongly, the mixing being proportional to the fermion mass, leading to a possibly large mass splitting between the two physical eigenstates $\tilde{t}_1$ and $\tilde{t}_2$ [4]. The top squark $\tilde{t}_1$ can be therefore much lighter than the other squarks and possibly lighter than the top quark itself.

If $\tilde{t}_1$ is lighter than the t–quark and the other SUSY particles [in particular the lightest chargino χ_1^+ and the charged and neutral scalar leptons $\tilde{\ell}$ and $\tilde{\nu}$] and assuming R–parity conservation with the lightest SUSY particle (LSP) being the neutralino χ_1^0, it will have only two decay modes. The first channel, which has been used to search for $\tilde{t}_1$ at LEP [5] and at the Tevatron [6] in the past, is the loop induced and flavor changing decay into a charm quark and the LSP neutralino, $\tilde{t}_1 \to c\chi_1^0$ [7]. The second channel is the four–body decay mode into a b–quark, the LSP and two massless fermions, $\tilde{t}_1 \to b\chi_1^0 f\bar{f}'$, which is mediated by heavier SUSY particle exchange [8]. The two modes are of the same order of perturbation theory, i.e. $\mathcal{O}(\alpha^3)$, and thus compete with each other.

However, $\tilde{t}_1$ might not be the next–to–lightest SUSY particle. In minimal Supergravity (mSUGRA) type models [3], where one assumes a universal mass m_0 for the scalar fermions and a common mass $m_{1/2}$ for the gauginos at the GUT scale, the scalar partner of the tau lepton, $\tilde{\tau}_1$, can become rather light for large enough values of $\tan\beta$ [the ratio of the vacuum expectation values of the two Higgs doublets needed to break the electroweak symmetry in the MSSM] and μ [the Higgs–higgsino mass parameter] and this might dramatically affect the pattern of $\tilde{t}_1$ decays.

Indeed if $\tilde{\tau}_1$ is lighter than the scalar top quark, the three–body channel $\tilde{t}_1 \to b\tilde{\tau}_1\nu_\tau$ will be kinematically accessible and would dominate the $c\chi_1^0$ decay mode [9]. For even larger $\tilde{t}_1$ masses, the two–body decay channel $\tilde{t}_1 \to b\chi_1^+$ would open up and overwhelm all other decays, and if $m_{\chi_1^+} \geq m_{\tilde{t}_1}$, the main decay mode of the lightest chargino would be $\chi_1^+ \to \tilde{\tau}_1\nu_\tau$ with $\tilde{\tau}_1$ decaying into $\tau\chi_1^0$ final states [10]. In fact, even if $m_{\tilde{\tau}_1} \gtrsim m_{\tilde{t}_1}$, the contribution of the diagram with $\tilde{\tau}_1$ exchange in the four–body decay mode will be large, since the virtuality of $\tilde{\tau}_1$ is smaller; the final state $\tilde{t}_1 \to b\chi_1^0\tau\nu_\tau$ would be then dominant.

Thus, for large $\tan\beta$ values and for stop masses of the order of 100–200 GeV which are accessible at the Tevatron Run II, the dominant decay mode of $\tilde{t}_1$ could be into a b–quark, the LSP neutralino and $\tau\nu_\tau$ pairs, i.e. with a final state consisting of a b–quark, a τ lepton and the missing energy due to the undetected LSP and neutrino. This topology is quite different from the ones which have been used to search for top squark pairs at the Tevatron up to now, i.e. two acoplanar jets plus missing energy for the mode $\tilde{t}_1 \to c\chi_1^0$ [6], one lepton plus missing energy for the mode $\tilde{t}_1 \to b\chi_1^+ \to b\chi_1^0 W \to b\chi_1^0\nu + e/\mu$ [the other W boson decaying hadronically], and two leptons, a $b\bar{b}$ pair and missing energy for the decay mode $\tilde{t}_1 \to b\ell\tilde{\nu}$ with $\ell = e/\mu$ [11], where the sneutrino decays invisibly [the chargino is assumed to be heavier] into the LSP neutralino and a neutrino.

In this note we will discuss the prospects for discovering the lightest top squark $\tilde{t}_1$ at the Tevatron Run II in the decay channel $b\tau + \not{E}$. After summarizing the decay branching ratios of $\tilde{t}_1$, we will discuss the cross sections of the signal $p\bar{p} \to \tilde{t}_1\tilde{t}_1^* \to b\bar{b}\tau^+\tau^- + \not{E}$, compared to those of the main background originating from top–quark pair production which has the same topology, $p\bar{p} \to t\bar{t} \to bW^+\bar{b}W^- \to b\bar{b}\tau^+\tau^-\nu\bar{\nu}$. We will show that by tagging one b quark and by requiring one τ lepton to decay leptonically and the other hadronically, and after suitable selections cuts, the discovery of top squarks with masses between 100 and 200 GeV is possible at the Tevatron, with a center of mass energy of 2 TeV and an integrated luminosity $\int \mathcal{L} \sim 20$ fb^{-1}.

2. Scalar top decays branching ratios

If top squarks are heavy enough, their main decay modes will be into top quarks and neutralinos, $\tilde{t}_i \to t\chi_j^0$ [j=1–4], and/or bottom quarks and charginos, $\tilde{t}_i \to b\chi_j^+$ [j=1–2]. If these modes are kinematically not accessible, the lightest top squark can decay into a charm quark and the lightest neutralino, $\tilde{t}_1 \to c\chi_1^0$ [7]. This mode is mediated by one–loop diagrams: vertex diagrams as well as squark and quark self–energy diagrams, where bottom squarks, charginos, charged W and Higgs bosons are running in the loops. The flavor transition $b \to c$ occurs through the charged currents. Adding the various contributions, a divergence is left out which must be subtracted by adding a counterterm to the scalar self–mass diagrams. When working in an mSUGRA framework where the squark masses are unified at the GUT scale, the divergence is subtracted using a soft–counterterm at Λ_{GUT}, generating a large residual logarithm $\log(\Lambda_{\mathrm{GUT}}^2/M_W^2) \sim 65$ in the amplitude. This logarithm gives the leading contribution to the $\tilde{t}_1 \to c\chi_1^0$ amplitude and makes the decay width rather large. [The decay width is though suppressed by the CKM matrix element $V_{cb} \sim 0.05$ and the (running) b quark mass squared $m_b^2 \sim (3 \text{ GeV})^2$].

However, there are scenarii in which the decay rate $\Gamma(\tilde{t}_1 \to c\chi_1^0)$ can be rather small. First, the large logarithm $\log(\Lambda_{\mathrm{GUT}}^2/M_W^2) \sim 65$ appears only because the choice of the renormalization condition is made at Λ_{GUT}, but in a general MSSM where the squark masses are not unified at some very high scale, one could chose a low energy counterterm; in this case no large logarithm would appear. In addition, if the lightest top squark is a pure right–handed state [as favored by the constrains [12] from high–precision electroweak data], the amplitude involves only one component which can be made small by choosing tiny values of the trilinear coupling A_b and/or large values of the (common) SUSY–breaking scalar mass $\tilde{m}_q$. Finally, even in the presence of stop mixing and for a given choice of MSSM parameters, large cancellations can occur between the various terms in the loop amplitude. Thus, the decay rate $\Gamma(\tilde{t}_1 \to c\chi_1^0)$ might be very small, opening the possibility for the three– or four–body decay modes to dominate.

The four–body decay mode $\tilde{t}_1 \to b\chi_1^0 f\bar{f}'$, proceeds through several diagrams, as shown in Fig. 1. There are first the W–boson exchange diagrams with virtual $\tilde{t}, \tilde{b}$ and $\chi_{1,2}^\pm$ states, a similar set of diagrams is obtained by replacing the W–boson by the H^+ boson and a third type of diagrams consists of up– and down–type slepton and first/second generation squark exchanges. The decay rate has been calculated in Ref. [8] taking into account all diagrams and interferences. The various contributions can be summarized as follows.

i) Because in the MSSM, $H^\pm$ has a mass larger than M_W and has tiny Yukawa couplings to light fermions, it does not give rise to large contributions. The squark exchange diagrams give also small contributions since squarks are expected to be much heavier than the $\tilde{t}_1$ state, $m_{\tilde{q}} \gtrsim \mathcal{O}(250)$ GeV [12]. The contribution of the diagram with an exchanged t–quark is only important if $m_{\tilde{t}_1}$ is of the order of $m_t + m_{\chi_1^0} \gtrsim \mathcal{O}(250$ GeV). *ii*) A significant contribution to the four–body decay mode would come from the first diagram in Fig. 1, when the virtuality of the chargino is not too large. In particular, for an exchanged χ_1^+ with a mass not much larger than the present experimental bound, $m_{\chi_1^+} \gtrsim 100$ GeV [12], the decay width can be substantial even for top squark masses of the order of 100 GeV. *iii*) In contrast to the exchange of squarks, slepton exchange diagrams might give substantial contributions, since masses $m_{\tilde{\ell}} \sim \mathcal{O}(100$ GeV) are still experimentally allowed [12]. In fact, when the difference between $m_{\tilde{t}_1}$ and $m_{\chi_1^+}, m_{\tilde{l}}$ is not large, the third diagram in Fig. 1 will give the dominant contribution to the four–body decay mode. In particular, if the τ slepton is rather light, the dominant final state will be $\tilde{t}_1 \to b\chi_1^0\tau\nu$.
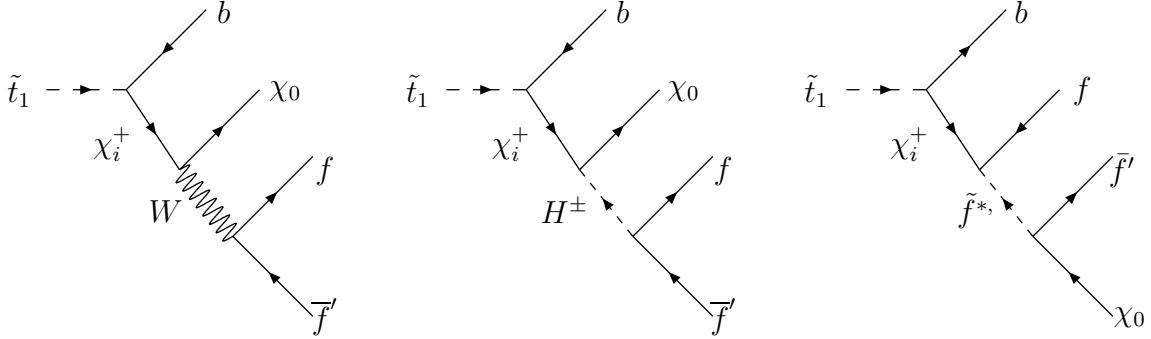

Figure 1: Generic Feynman diagrams contributing to the decay $\tilde{t}_1 \to b\chi_1^0 f\bar{f}'$.

For larger stop masses, when the W boson, the $H^\pm$ boson and/or the sfermion $\tilde{f}^*$ in Fig. 1 are kinematically allowed to be on mass–shell, one will have a three–body decay mode of the $\tilde{t}_1$. These modes have been discussed earlier in Refs. [9] but the case of the $\tilde{\tau}_1$ state, which might be rather light as mentioned previously, has not been discussed explicitly. However, this is potentially the dominant mode since the other modes can be strongly suppressed: the $H^\pm$ boson is expected to be rather heavy and its couplings to fermions [except from tb states which are not kinematically accessible] are rather tiny, and if the lightest chargino and neutralino are gaugino like [as is usually the case in mSUGRA–type models] the $W\chi_1^0\chi_1^+$ coupling is very small. Thus, even if the three channels are present at the same time, the decay $\tilde{t}_1 \to b\tilde{\tau}_1\nu$ with the subsequent decay $\tilde{\tau}_1 \to \tau\chi_1^0$ [which is the only possible channel since $m_{\chi_1^+} > m_{\tilde{\tau}_1}$ and the decay $\tilde{\tau}_1 \to \nu_\tau\chi_1^+$ is kinematically shut] could be the dominant decay mode of the lightest top squark.

Finally, if $m_{\tilde{t}_1} > m_{\chi_1^+} + m_b$, the two–body decay channel $\tilde{t}_1 \to b\chi_1^+$ will be kinematically accessible and would dominate all other possible modes. But if $\tilde{\tau}_1$ is light, the chargino will dominantly decay into $\tilde{\tau}_1\nu_\tau$ pairs [10]. The other possible decay mode $\chi_1^+ \to \chi_1^0 W$, if accessible, would be suppressed by the small $W\chi_1^0\chi_1^+$ coupling which vanishes for pure gaugino–like charginos and neutralinos. For even higher masses, $m_{\tilde{t}_1} \gtrsim \mathcal{O}(250)$ GeV, the decay channel $\tilde{t}_1 \to t\chi_1^0$ opens up, and would compete with the previous decay mode.

Thus in all these situations, the possibly dominant decay mode of the lightest scalar top quark, with a mass below $m_t + m_{\chi_1^0} \gtrsim 200$ GeV, would be into $b\chi_1^0\tau\nu$ final states. This is illustrated in Fig. 2 where we show the branching ratio for this final state as a function of $m_{\tilde{t}_1}$ for two values of $\tan\beta = 5$ and 20 in an approximate mSUGRA–type model. We have assumed gaugino mass unification and a common mass m_0 for all scalar fermion at the GUT scale, except for $m_{\tilde{t}_R}$ which is varied to obtain $\tilde{t}_1$ masses between 100 and 200 GeV. The parameter μ is fixed to a high value, $\mu = 750$ GeV, to generate a large mixing in the $\tilde{\tau}$ sector to obtain a light $\tilde{\tau}_1$ state; in this case the lightest chargino and neutralino are wino– and bino–like with masses, $m_{\chi_1^+} \simeq 2m_{\chi_1^0} = M_2$. The trilinear couplings $A_{t,b}$ are fixed to values of $\mathcal{O}(100$ GeV$)$. With the inputs $M_2 = 170$ GeV, $m_0 = 170\,(100)$ GeV for $\tan\beta = 20\,(5)$, one obtains for the chargino and τ slepton masses: $m_{\chi_1^+} \simeq 2m_{\chi_1^0} \sim 165$ GeV and $m_{\tilde{\tau}_1} \sim 130$ GeV. All sparticles [as well as the $H^\pm$ boson] have large enough masses not to affect the decay branching ratio, except for the charged sleptons $\tilde{e}, \tilde{\mu}$ and the sneutrinos $\tilde{\nu}$ which have masses only slightly above $m_{\chi_1^+}$ in the $\tan\beta = 5$ scenario.

As can be seen, for $\tan\beta = 20$, the final state $b\chi_1^0\tau\nu$ is dominant in almost the entire range of $m_{\tilde{t}_1}$, in particular when the three–body decay mode $\tilde{t}_1 \to b\tilde{\tau}_1\nu$ and the two–body decay mode $\tilde{t}_1 \to b\chi_1^+$ open up [the spikes correspond to the opening of these channels, the finite widths of the virtual particles not being included]. For the four body–decay mode, BR$(\tilde{t}_1 \to b\chi_1^0\tau\nu)$ reaches values of the order of 50% for $m_{\tilde{t}_1} \gtrsim 100$ GeV; below this value, BR$(\tilde{t}_1 \to c\chi_1^0)$ [which is enhanced by $\log^2(\Lambda_{\text{GUT}}^2/M_W^2)$ and a factor $\tan^2\beta$] is dominant because of the larger phase space [here $m_{\tilde{t}_1} \sim m_b + m_{\chi_1^0}$]. For the small value $\tan\beta = 5$, the decay $\tilde{t}_1 \to b\chi_1^0\tau\nu$ is dominant only for masses $m_{\tilde{t}_1} \gtrsim 150$ when the channel $\tilde{t}_1 \to b\chi_1^+$ is about to open up. Below this value, there is a competition from the channels with the W exchange diagram [here, $m_{\chi_1^+} \sim m_{\chi_1^0} + M_W$] and with the exchange of the other sleptons [which have masses close to $m_{\chi_1^+}$]. In this case, BR$(\tilde{t}_1 \to b\chi_1^0\tau\nu)$ is too small, and one has to rely on the decays involving e, μ final states [11, 13].
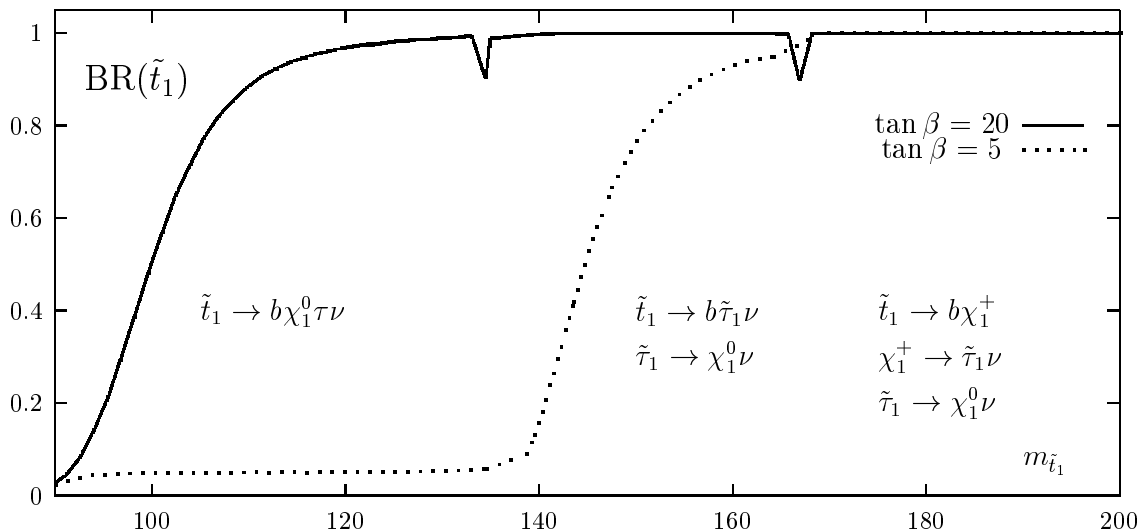

Figure 2: *The branching ratio $BR(\tilde{t}_1 \to b\chi_1^0\tau\nu)$ versus $m_{\tilde{t}_1}$ for $\tan\beta = 5$ and 20. The SUSY parameters are such that $m_{\chi_1^+} \simeq 2m_{\chi_1^0} \simeq 165$ GeV and $m_{\tilde{\tau}_1} \simeq 130$ GeV.*

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3. Scalar top production: signal and backgrounds

Top squarks are produced in hadronic collisions via quark–antiquark annihilation and gluon–gluon fusion [14]. The total cross section at the Tevatron with $\sqrt{s} = 2$ TeV is of the order of $\sigma(p\bar{p} \to \tilde{t}_1 \tilde{t}_1^*) \sim 15$ to 0.3 pb for $\tilde{t}_1$ masses in the range of 100 to 200 GeV. A factor $K \sim 1.3$, to take into account the next–to–leading order QCD corrections [15], has been included. The renormalization scale has been chosen at $\mu^2 = m_{\tilde{t}_1}^2$ and the CTEQ3L [16] parameterization of the parton densities has been used. This has to be compared with the production cross section of top quark pairs, $\sigma(p\bar{p} \to t\bar{t}) \sim 8$ pb, which includes the factor $K \sim 1.4$ for QCD corrections [17].

In the following, we will chose the scenario discussed in the previous section, i.e. with the lightest chargino, neutralino and $\tilde{\tau}_1$ masses being $m_{\chi_1^+} \simeq 2m_{\chi_1^0} \simeq 165$ GeV and $m_{\tilde{\tau}_1} \simeq 130$ GeV, and assume that top squarks will decay into $b\chi_1^0 \tau \nu_\tau$ final states with a branching ratio close to unity. Therefore, pair production of top squarks leads to final states containing two b–quarks, a $\tau^+\tau^-$ pair and missing transverse energy.

This final state can be triggered by selecting $b\tau_\ell\tau_h + \not{E}_T$, where we assume that one τ lepton decays leptonically, with a branching ratio $\mathrm{BR}(\tau^\pm \to e^\pm + \mu^\pm) \simeq 35\%$, while the other decays hadronically with $\mathrm{BR}(\tau^\pm \to \text{hadrons}) \simeq 65\%$. The hadronic τ jets can be tagged as narrow jets with their three main decay modes being $\tau^\pm \to \pi^\pm \nu_\tau$ (18%), $\tau^\pm \to \rho^\pm \nu_\tau$ (24%) and $\tau^\pm \to a_1^\pm \nu_\tau$ (7.5%). Each vector meson (a_1, ρ) decays hadronically in one charged pion and other neutral pions signaling 1–prong decay modes in the detector. The decay distribution is normalized according to the decay modes following the prescription given in Ref. [18]. The cross section will be diluted by the branching ratio suppression for $\tau\tau \to \ell\tau_h$ by $B_{\ell\tau_h} = 0.35 \times 2 \times (2/3) \simeq 45\%$ for $\ell = e, \mu$. Of course, to increase the statistics, one could also use the topology where both tau leptons decay hadronically which has a larger branching ratio than the $\tau_h\tau_\ell$ mode; this channel, although viable [20], will not be discussed in this note.

We have calculated the signal [and main background] cross sections by using a simple parton–level Monte–Carlo simulation, i.e. without taking into account fragmentation effects of jets. For for the selection of the signal events, we use the following set of cuts for the transverse momentum p_T, the rapidity η and the lepton/jet isolation cut defined as $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ with $\Delta\eta$ and $\Delta\phi$ being, respectively, the difference of rapidity and azimuthal angle between the leptons and any of the jets:

1. Lepton selection: $p_T^\ell > 7$ GeV and $|\eta_\ell| < 2$ with $\Delta R > 0.4$.
2. τ jet selection: $p_T^\tau > 10$ GeV and $|\eta_\tau| < 4$ with $\Delta R > 0.5$.
3. Missing energy selection: $\not{p}_T > 15$ GeV.
4. b–jet selection: number of b-jets ≥ 1 with $p_T^b > 15$ GeV, $|\eta_b| < 4$ and $\Delta R > 0.7$.

The cross section for the signal after successively applying these cuts are shown in Table 1 for several values of $m_{\tilde{t}_1}$. The cut "0" stands for the total production cross section times the branching ratio for one τ decaying leptonically and the other decaying hadronically [BR $\sim 45\%$]. The cuts are much harder in the case of light top squarks than for heavier ones: while the cross section is suppressed by three orders of magnitude for $m_{\tilde{t}_1} \sim 100$ GeV, there is only a factor of two suppression for $m_{\tilde{t}_1} \sim 200$ GeV. This is

Cut ↓ / $m_{\tilde{t}_1}$ →	100	120	150	180	200	$t\bar{t}$
0	7.2	2.7	.76	.25	.13	.26
1	.39	.57	.52	.17	.09	.24
2	.20	.09	.36	.12	.06	.14
3	.006	.06	.30	.10	.058	.14
4	.004	.044	.16	.07	.057	.14
$H_T < 100$ GeV	.004	.043	.10	.046	.032	.016

Table 1: *The $\tilde{t}_1\tilde{t}_1^*$ signal and $t\bar{t}$ background event cross sections [in pb] after the selection cuts 0–4 and the H_T cut have been applied.*

mainly due to the fact that, in the chosen scenario, the mass of the LSP, $m_{\chi_1^0} \sim 80$ GeV, is too close to $m_{\tilde{t}_1}$ so that the b quarks and τ leptons are much softer in the former case. For lighter neutralinos or heavier top squarks, the cuts are much less severe.

The main sources of background, besides $t\bar{t}$ pair production, are gauge boson pair production: $p\bar{p} \to W^+W^-, W^\pm Z, ZZ$ and $Z\gamma$, plus eventually some QCD jets. All these background processes can be removed by requiring a fair amount of missing transverse energy as well as at least one b–quark jet and two tau leptons, since the probabilities for misidentifying jets with b–quarks and τ–leptons is very small [19]. For instance, in the case of W–pair production which has the largest cross section, $\sigma(p\bar{p} \to W^+W^-) \sim 11$ pb, requiring a final state $\ell\nu q\bar{q}'$ plus an additional soft QCD jet faking a τ–jet, the cross section drops to the level of 0.2 pb after imposing the selection cuts discussed previously. Assuming probabilities of misidentifying the jets as τ_h and b–quarks of a few percent [19], the cross section will be suppressed by at least three orders of magnitude, well below the level of the signal cross section even for $m_{\tilde{t}_1} \sim 100$ GeV.

Therefore, one should be left only with the $t\bar{t}$ background process. The total production cross section, $\sigma(p\bar{p} \to t\bar{t}) \sim 8$ pb, should be multiplied by the total branching suppression factor which leads to the relevant $b\bar{b}\tau_h\ell + \not{E}$ final state [in $t\bar{t} \to b\bar{b}W^+W^-$ one W boson decays into e/μ while the other decays into a τ lepton which then decays hadronically], that is $B_{t\bar{t}} \simeq (2/9) \times (1/9) \times (2/3) \times 2 \simeq 0.032$, leading to a cross section of $\sigma \sim 0.26$ pb in this final state.

The cross sections times branching ratio for the $t\bar{t}$ background, after the successive cuts discussed above, are also shown in Table 1. As can be seen, it is possibly larger than the signal cross section, especially for light stops. To suppress further this background we apply the cut: $H_T < 100$ GeV where $H_T = |p_\ell^T| + |p_{\tau_h}^T| + |\not{p}_T|$. Since all these transverse momenta for $t\bar{t}$ production are harder than in the case of the signal events for range of stop masses accessible at the Tevatron, this reduces the $t\bar{t}$ background significantly. As for example, after this cut, the $t\bar{t}$ cross section is suppressed by one order of magnitude and finally leads to a background cross section of 16 fb. In the case of the signal, this cut is harmless as shown in Table 1.

The final output is displayed in Fig. 3, where the signal cross section[1] after all cuts is shown as a function of $m_{\tilde{t}_1}$. Ones sees that for $m_{\tilde{t}_1} \gtrsim 100$ GeV, $\sigma(\tilde{t}_1\tilde{t}_1^* \to b\bar{b}\tau_\ell\tau_h + \not{E})$ is larger than 10 fb and reaches a maximum of ~ 100 fb for $\tilde{t}_1$ masses between 120 and 170 GeV. The $t\bar{t}$ background, $\sigma(t\bar{t}) \sim 16$ fb, is much smaller after all cuts have been applied. One has then to multiply these numbers by the b–quark and τ lepton tagging efficiencies, which are expected to be of the order of 50% [19, 20] and which leads to a further suppression[2] of the signal events by a factor of 4. This means that more than 10 (100) events in this topology can be collected for stop masses in the range 120 GeV $\lesssim m_{\tilde{t}_1} \lesssim 180$ GeV, with an integrated luminosity of 2 (20) fb^{-1} as expected in the two runs of the Tevatron[3]. Therefore, one could hope to observe top squark events in this channel at the Tevatron, at least in the high–luminosity option.
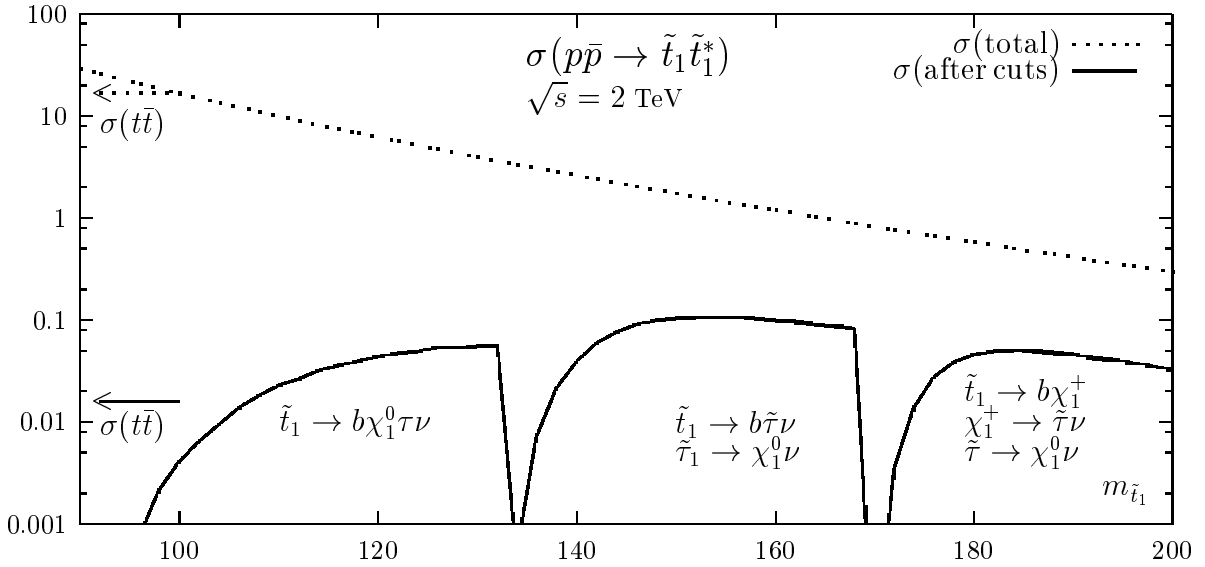

Figure 3: *The cross sections for $p\bar{p} \to \tilde{t}_1\tilde{t}_1^*$ in pb at the Tevatron as a function of $m_{\tilde{t}_1}$: the dashed lines are the total cross section and the solid lines for the cross section after selection cuts (see text). The cross sections for $t\bar{t}$ production are indicated by the arrows.*

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[1]The spikes are again due to the opening of the three–body and two–body decay channels, where the phase space for the decays $\tilde{t}_1 \to b\tilde{\tau}_1\nu$ and $\tilde{t}_1 \to b\chi_1^+$ is very small, leading to very soft b–quark jets. This is quite artificial since, if the finite decay widths of the chargino and τ slepton are included in the decay amplitudes, there will be a smooth transition between the 4–body to the 3–body to the 2–body decay branching ratios. These decay widths have not been included in the analysis since for the integration of the complicated 4–body phase space, we use a Monte–Carlo which is not enough precise to resolve the tiny total widths [compared to the masses] of the exchanged SUSY particles.

[2]In fact, there is no need for b–tagging since with the cut 4, $p_T^{\mathrm{jet}} > 15$ GeV, the backgrounds with gauge boson production will be suppressed to a negligible level [20]. However, since very efficient micro–vertex detectors will be available in both CDF and D0, it is safer to require the presence of a b–jet.

[3]As mentioned previously, the problem in the lower stop mass range is mainly due to the small $m_{\tilde{t}_1} - m_{\chi_1^0}$ difference which leads to very soft b quarks and τ leptons that do not pass the selection cuts. For lighter neutralinos, the phase space would be larger and the signal cross section can be enhanced to a visible level. For the high stop mass range, $m_{\tilde{t}_1} \gtrsim 200$ GeV, one is simply limited by the smallness of the production cross section.

4. Discussions and conclusions

We have shown that in the large $\tan\beta$ regime, scalar top quarks that are accessible at the Run II of the Tevatron [i.e. with masses in the range of 100 to 200 GeV] might decay predominantly into bottom quarks, τ leptons and a large amount of missing energy due to the escaping neutrinos and neutralinos. This is due to the fact that τ sleptons are also relatively light: either the decay channels $\tilde{t}_1 \to b\tilde{\tau}_1\nu_\tau$ and $\tilde{t}_1 \to b\chi_1^+ \to b\tilde{\tau}_1\nu_\tau$ are kinematically open, or the virtuality of the exchanged τ sleptons in the four–body decay channel is small making the final state, $\tilde{t}_1 \to b\chi_1^0\tau\nu$ dominant.

We have performed a crude estimate of the prospects for discovering such a light scalar top quark in the $p\bar{p} \to \tilde{t}_1\tilde{t}_1^* \to b\bar{b}\tau^+\tau^- + \not{E}$ channel at the Run II of the Tevatron. Requiring one of the τ leptons to decay leptonically and the other hadronically and the tagging of one b–quark [with reasonable efficiencies], and applying rather loose cuts to select the signal, we have shown that this signal can give a substantial number of events, in particular in the high luminosity option $\int \mathcal{L} \sim 20$ fb^{-1}, and that it can stand over the background, which is dominantly due to top quark pair production in the channel $p\bar{p} \to t\bar{t} \to b\bar{b}\tau\ell + \nu\bar{\nu}$. A detailed analysis taking into account all backgrounds, selection and detection efficiencies in a more realistic way, which is beyond the scope of this short note, is nevertheless required to assess in which part of the MSSM parameter space this final state can be isolated experimentally.

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